

STANDARDS DEVELOPMENT AT NASA WHITE SANDS TEST FACILITY*

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ABSTRACT

The development of standards and standard activities at the JSC White Sands Test Facility (WSTF) has been expanded to include the transfer of technology and standards to voluntary consensus organizations in five technical areas of importance to NASA. This effort is in direct response to the National Technology Transfer Act designed to accelerate transfer of technology to industry and promote government-industry partnerships. Technology transfer is especially important for WSTF, whose long-term mission has been to develop and provide vital propellant safety and hazards information to aerospace designers, operations personnel, and safety personnel. Meeting this mission is being accomplished through the preparation of consensus guidelines and standards, propellant hazards analysis protocols, and safety courses for the propellant use of hydrogen, oxygen, and hypergols, as well as the design and inspection of spacecraft pressure vessels and the use of pyrovalves in spacecraft propulsion systems. The overall WSTF technology transfer program is described and the current status of technology transfer activities are summarized.

INTRODUCTION

Following passage of the Technology Transfer and Advancement Act of 1995 (NTTAA)¹, government, academia, and industry have focussed on expanding technical interchange through voluntary consensus organizations. This action comes at a time of significant changes in the aerospace environment. Changes include reorganization in the aerospace industry, reduction in force within government, greater standards coordination at an international level, replacement of military (MIL) specifications with performance specifications, and conversion of government guidelines and standards with voluntary consensus standards. To keep pace with these changes, NASA White Sands Test Facility (WSTF) has evolved a model of technical interchange that recognizes the synergy and interrelationship between the fundamental aerospace activities of research, hazard analysis, and training with the development of standards for aerospace fuel, operations, and systems. This model is being developed for safety standards contributions involving propellants (hydrogen, hypergol, and oxygen), composite pressure vessels, and pyrovalves. Concurrent with these WSTF aerospace activities are related technology transfer efforts to develop non-aerospace standards, publish propellant hazards analysis protocols, and provide safety courses for industry and other sectors of the economy.

This paper reports on these efforts and describes WSTF's overall voluntary consensus standards program to coordinate the interchange of NASA's propellant hazards and safety information with industry and the public.

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A NEW AND CHANGING ENVIRONMENT

The rapid pace of transfer of government activities to the aerospace industry, along with the increasing incidence of aerospace corporate mergers, have the potential for disrupting coordination and flow of vital propellant safety and hazards information among personnel involved in design, operations, and safety of propellant systems. Within this setting exist the risks associated with employees' potential exposure to hazardous chemicals in governmental and industrial work environments. The latter has led to detailed governmental regulations that specify a highly trained work force, the use of hazards review methodologies, hazards communications with employees and the surrounding community, and adequate emergency preparedness. How can the effects of these potentially opposing forces be countered?

Consensus as a Means of Communication

One response is for government and industry to cooperate within the framework provided by a Voluntary Consensus Organization (VCO), which acts as a clearinghouse for critical information, helps identify top expertise, and offers training. The democratic structure of VCOs enables them to develop voluntary consensus standards that meet the needs of both government and industry. Easily leveled criticisms of standards efforts conducted within government agencies are that the results are inadequate, one-sided, and inaccessible. The NTTAA has forced government to reevaluate its standards efforts. But for NASA, an agency that has been always been proactive with regard to public outreach and technology transfer, NTTAA provides the basis for even greater interaction with industry and the public.

Aside from the primary goal of managing standards through a VCO, other positive attributes should arise from pursuit of the law. These attributes include improved communication within government agencies and between industrial entities, as well as interagency/interindustry connections. This has the potential to bring different interests together and lead to the establishment of a common ground in which research and development can take root. It is likely that VCOs will continue to be a focal point for general information related to voluntary consensus standards, such as identifying where particular expertise can be found.

NASA's interest in participation with VCOs in the safety arena includes the transfer of hazards manuals and the development of voluntary consensus standards. In theory, hazards information is better distributed by VCOs, with the cost being covered by the program interests that need the information rather than subsidized by the government. One goal is to promote the creation of general safety standards for propellant use that can be applied in government-industry contract negotiations.

For agencies that are not proactive in response to NTTAA, it will be interesting to see how the law will work in the future. The Office of Management and Budget (OMB) requires federal agencies to report on the status of their efforts to meet the law. Already the mobile home construction industry has brought a legal challenge² against legislation pending in Congress, the American Homeownership and Opportunity Act, H.R. 1776, citing conflicts with NTTAA. The industry is claiming that preexisting law directs them through VCOs to keep standards for manufactured homes up-to-date and the new law is not needed.

New Developments

Changes have continued in recent years that more than ever point to the need for voluntary consensus standards. Government continues to reduce the civil service resources and this has led to several effects. NASA often relies on project teams staffed by both government and contractor team members operating at a greater level of integration than practiced in the past. In addition, downsizing has made single-project orientation of an organization no longer feasible. Not only must NASA program managers run multiple projects, they must also share work with contractor team members and serve clients in other branches of government or private industry. Further, organizations must consider a wide variety of work supported by multiple-fund sources from both government and industry to keep the best talent available. Different kinds of changes are affecting the aerospace industry, including a recent turnover in the suppliers of hypergolic fuels.

By design, NTTAA has prompted a new, more cooperative environment between government and industry that accelerates technology transfer to industry and promotes government-industry partnerships. But technology transfer from government to industry involves more than simply relaying scientific data and technology development. It also involves sharing hazards review and training expertise and making the information and techniques used by government laboratories more accessible to industry and the public. Technology transfer activities also drive government efforts to be more attuned to industry needs. In all of these areas, the improved connectivity, communications, and consensus on issues provided by VCOs will help smooth the transition inherent with the changing environment.

WSTF TECHNOLOGY DEVELOPMENT IN SUPPORT OF STANDARDS

WSTF has been involved with testing of hazardous fluids, components, and materials in direct support of NASA safety standards since 1966. The emphasis has been on the safe use of aerospace fuels and oxidizers. This work has included material compatibility testing, fuel ignition testing, and explosion testing. More recently, work on composite pressure vessels (COPV) and pyrovalves has been conducted in support of standards. With the new direction prompted by NTTAA, a relationship among research and development, hazards analysis protocols, safety course development, voluntary consensus standards activities, and industry communications has become apparent.

Interrelationship of Standards Development, Hazard Analysis, Research, and Training

The process of technology transfer at WSTF (Figure 1) shows standards development proceeding with information input from "Research and Development", "Hazards Analysis", and "Safety Courses." The hazards analysis process is depicted at the center of the overall technology transfer process as the information gained by hazards analyses can serve as input to VCOs, research, and training. Conversely, VCO committees, research groups, and trainers can have influence on hazards analysis protocols. For this scheme to function effectively, some group in industry or government must have a vested interest in tracking, documenting, and communicating key information obtained from the use of hazards analysis protocols. At present, WSTF is funded to do this work. A logical extension of who performs this sort of work would include the VCOs themselves.

One of WSTF's primary goals is to support NASA's propellant safety efforts, which involve testing, research and development, and hazards analysis of cryogenic and hypergolic propellants. These activities are organized to support queries from industry and the public, provide training to those who need it, and collaborate with VCOs to develop voluntary consensus standards. Important insights into the role hazards analyses can play in the overall direction and planning of safety research have become apparent. WSTF is recognized throughout NASA and the aerospace community for its formalized approach to oxygen hazards analysis, and has designed other protocols for application to hydrogen, hydrazine fuels, and nitrogen tetroxide.

WSTF Hazards Analysis Support Services

In their traditional roles, project- and program-oriented groups use hazard analysis as a means of identifying and remediating potential component and system inadequacies. But sometimes during the course of an analysis, a need arises for data that do not exist. For example, the assessment of propellant hazards may involve the need for combustion or materials data that are not currently available but can be gained through testing. But if the team determines that testing is too difficult or expensive, the analysis might prompt a system redesign, the acceptance of greater risk, or a new method for assessing the hazards. Therefore, hazard analysis can be considered a tool that provides knowledge about what we need to know.

Several specialized hazard analysis protocols have been developed at WSTF to analyze detailed system data and efficiently document hazards information. These protocols work by identifying operating conditions, examining in detail all components and materials exposed to a particular propellant, analyzing likely failure modes involving flammability and ignition, determining the consequence(s) of a particular

failure to the system, and qualitatively assessing the risk for the system owners. The benefits derived from this analysis go beyond identifying hazards. Design teams have a better understanding of their systems. The system “owners” and the design teams are much better prepared for higher-level reviews. Higher-level review teams have shown great respect for the protocols because of their rigor.

Protocols for oxygen, hydrogen, and hypergols have been established, and a protocol for pyrotechnics is under discussion. The protocols address primarily combustion hazards. The protocols are backed by safety databases established and maintained by WSTF. Hazards analysis services have been provided by WSTF to government and industry over the past 15 years. Within NASA, use of the protocols has met with an overwhelmingly positive response. Protocol descriptions available from WSTF upon request are:

- ASTM G63, “Guide for Evaluating Nonmetallic Materials for Oxygen Service”³
- ASTM G88, “Guide for Designing Systems for Oxygen Service”⁴
- ASTM G94, “Guide for Evaluating Metals for Oxygen Service”⁵
- TP-WSTF-937, “Guide for Hydrogen Hazards Analysis on Components and Systems”⁶
- TP-WSTF-953, “Guide for Hydrazine Hazards Analysis on Components and Systems”⁷
- TP-WSTF-959, “Guide for Nitrogen Tetroxide Hazards Analysis on Components and Systems”⁸

Training Support Services

WSTF has provided safety training courses in specialized areas for over 15 years. The course materials have been developed to meet the requirements of the NASA Safety Training Center (NSTC). The courses include:

- Oxygen Safety Classes* (4): ASTM Technical and Professional Training Course, “Fire Hazards in Oxygen Systems”⁹ (several versions exist that are tailored to particular audiences, such as design engineers, technicians, and the scuba community)
Oxygen Systems Operation and Maintenance
Oxygen Systems Management, Design, Operation and Maintenance
ISS Oxygen Systems Assembly, Operations, and Maintenance
- Hypergol Safety Class (1): NSTC 055, Hypergol Systems: Design, Buildup, & Operation
- Hydrogen Safety Classes (2): NSTC 054, Hydrogen Safety Operations
NSTC 037, Hydrogen Safety
- COPV Inspection Class (1): Inspection for Damage to Carbon/Epoxy Composite Overwrapped Pressure Vessels

The courses have been taught at various government and industrial locations. Within NASA, they are available through the NSTC. For non-NASA government groups and private industry, the safety classes are available directly through WSTF. The oxygen classes are taught through the American Society for Testing and Materials (ASTM).

JSC WSTF STANDARDS DEVELOPMENT AND TECHNOLOGY TRANSFER PROGRAM

Special responsibilities for COPV, hydrogen, hypergol, oxygen, and pyrovalve standards development reside at WSTF. The overall responsibility for standards transfer at NASA rests with the NASA Engineering Standards Steering Council (NESSC). WSTF participates directly with the NESSC but also receives specific tasks from the NASA Office of Safety and Mission Assurance (HQ/OSMA) (Code Q).

* Courses are offered by ASTM as a part of their program of ASTM Technical and Professional Training. The NSTC coordinates NASA courses through ASTM. Instructors are from WSTF.

The process of standards development as it applies to technology transfer of in-house NASA standards can be considered as occurring in three phases as shown in Figure 1. Phase I begins with direction from Code Q and a survey of VCOs. The VCOs identified as candidates to host the standards are contacted. One is selected based on a match of the VCO's goals with NASA's goals and their ability to meet publication requirements. In Phase II, the committee and its business are developed. The VCOs host committee meetings, coordinate committee activities, and help publish special reports, technical guides, and consensus standards. Standards maintenance and participation become a routine element of WSTF participation in Phase III.

At present, oxygen standards activities are performed through the ASTM, the National Fire Protection Association (NFPA), and the International Standards Organization (ISO). Hydrogen standards development is performed through the American Institute for Aeronautics and Astronautics (AIAA), the National Hydrogen Association (NHA), and ISO. Hypergolic standards are developed through AIAA. Pressure vessel and pyrovalve standards are also being developed through AIAA.

Accomplishments to Date

WSTF's parallel efforts to promote safety research and develop safety standards have become a vital part of its mission. This section outlines specific achievements in the standards areas.

Propellant Oxygen

Research into propellant oxygen hazards has been ongoing at WSTF since the mid-1970s and is its most mature expression of the interrelationship among research, hazards analysis, and VCO participation. Technical communications and technology transfer with industry are achieved through long-standing participation with ASTM Committee G4 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and the NFPA committees on Health Standards and Hyperbaric Standards. The oxygen hazards analysis protocol has been in use for over a decade. WSTF researchers have developed an oxygen safety training course, "Fire Hazards in Oxygen Systems,"⁹ that is offered through ASTM. At the request of the NASA HQ/OSMA, WSTF developed a safety standard for oxygen and subsequently collaborated with ASTM to publish it as Manual 36, "Safe Use of Oxygen and Oxygen Systems."¹⁰ WSTF's progress in the oxygen arena serves as a model for its development of hydrogen and hypergol propellant programs. The following documents are available for oxygen safety assessment:

- ASTM MNL36, "Safe Use of Oxygen and Oxygen Systems"¹⁰
- NASA Safety Standard 1740.15, "Safety Standard for Oxygen and Oxygen Systems"¹¹
- NASA Technical Memorandum 104823, Guide for Oxygen Hazards Analyses on Components and Systems"¹²
- NFPA 53, "Recommended Practice in Oxygen-Enriched Atmospheres"¹³

Propellant Hydrogen

WSTF participates in the development of both aerospace and general hydrogen safety standards. This work is performed in cooperation with AIAA, NHA, and ISO Technical Committee 197 Hydrogen Technologies (ISO/TC 197).

To develop aerospace hydrogen standards, WSTF has worked to form the AIAA Hydrogen Committee on Standards (HCOS). This committee seeks to identify aerospace hydrogen safety concerns, develop safety documents where needed, and promote the dissemination of hydrogen safety information. Committee membership includes representatives from academia, the aerospace industry, DOE, DOD, FAA, hydrogen suppliers, and NASA. The HCOS is currently working to assess the need for hydrogen safety standards in the aerospace community. NASA has an interest in the development of a general hydrogen safety standard that could be cited to establish acceptable practice in contracts. Toward that end, the HCOS is working to publish a consensus guide based on the NASA hydrogen safety standard. Because of the intense interest in hydrogen safety beyond aerospace applications, the HCOS maintains

liaisons with the NHA and ISO. Ultimately, the HCOS will seek to promote AIAA documents as national aerospace standards.

In a parallel effort, WSTF works with the NHA on national hydrogen safety issues and with ISO/TC 197 to promote the development of international hydrogen safety standards. These activities began in 1998 when NASA was invited by the DOE and the NHA to help represent U.S. trade interests by contributing hydrogen safety expertise to work with the international community to develop hydrogen standards for commerce. Recent accomplishments include WSTF's contribution to Working Group 7 for the development of the final draft of ISO/PDTR 15916, "Basic considerations for the safety of hydrogen systems." This document will serve as the cornerstone safety document for ISO hydrogen standards for commerce. Reinforcing this involvement with general hydrogen standards is the request by both the AIAA Standards Executive Council and the NASA Engineering Standards Steering Council (NESSC) for the AIAA HCOS to consider the relationship and synergy between general hydrogen and aerospace hydrogen standards. WSTF regularly contributes presentations at NHA/DOE forums and expertise to support work on national hydrogen standards development. This participation has evolved to include issues involving hydrogen storage within composite pressure vessels. The following documents are or soon will be available for use:

- NASA Safety Standard 1740.16, "Safety Standard for Hydrogen and Hydrogen Systems"¹⁴
- RD-WSTF-0001, "Ignition and Thermal Hazards of Selected Aerospace Fluids"¹⁵
- AIAA Hydrogen Safety Guide (publication planned for 2003)
- ISO/PDTR 15916, Basic Considerations for the Safety of Hydrogen Systems (subject to international approval, Fall 2002)

Hypergolic Fuels and Oxidizers

Progress in the hypergol safety arena parallels WSTF's oxygen and hydrogen efforts in that several manuals covering the hazards of hypergolic propellants have been developed at WSTF. This is just the kind of information that could better serve the aerospace community if it was managed by a VCO. In collaboration with AIAA, WSTF promoted the formation of the recently initiated AIAA Liquid Propellant Committee on Standards (LPCOS) to serve as a forum for discussion of hypergolic and related propellant safety issues. This committee has an agenda to oversee the development of voluntary consensus standards covering hydrazine, monomethylhydrazine, dinitrogen tetroxide, and other aerospace fluids of interest. WSTF hypergolic hazards manuals have been transferred to AIAA for distribution as AIAA Special Projects. The agreement stipulates that needed updates of hypergolic hazards information will be published through AIAA Special Projects or Guides. In addition to the AIAA committee work, JSC has funded development of a hazards analysis protocol for hypergolic propellants. Also, NASA HQ/OSMA has funded WSTF for development of a hypergol safety training course. The following documents are available for hypergolic safety assessment:

- RD-WSTF-0001, "Ignition and Thermal Hazards of Selected Aerospace Fluids"¹⁵
- RD-WSTF-0002, "Fire, Explosion, Compatibility, and Safety Hazards of Hydrazine"¹⁶
- RD-WSTF-0003, "Fire, Explosion, Compatibility, and Safety Hazards of Monomethylhydrazine"¹⁷
- RD-WSTF-0017, "Fire, Explosion, Compatibility, and Safety Hazards of Nitrogen Tetroxide"¹⁸
- AIAA SP-084-1999, "Fire, Explosion, Compatibility, and Safety Hazards of Hypergols – Hydrazine"¹⁹
- AIAA SP-085-1999, "Fire, Explosion, Compatibility, and Safety Hazards of Hypergols – Monomethylhydrazine"²⁰
- AIAA SP-086-2001, "Fire, Explosion, Compatibility, and Safety Hazards of Nitrogen Tetroxide"²¹

There is also a current effort to develop a technical manual for hydrogen peroxide.

Pressure Vessel Standards

WSTF conducted an extensive testing program that involved developing a database to evaluate impact damage to composite overwrapped pressure vessels (COPVs) used in space vehicle applications. This database provides the basis of a WSTF training course entitled "Inspection for Damage to Carbon/Epoxy Composite Overwrapped Pressure Vessels." These data were used to establish a standard for COPVs sponsored by an AIAA Pressure Vessel Standards Working Group. WSTF technical personnel participate in this working group in the maintenance of the following AIAA pressure vessel standards:

- Metal pressure vessels
- Composite overwrapped pressure vessels
- Composite structures
- Solid rocket motor case
- Composite pressure vessels
- Composite overwrapped pressure vessels with nonmetallic liners.

Pyrovalve Standard

A WSTF research and development program directed towards establishing a technical database to assure the safe use of pyrovalves in space vehicles is relatively new. Our initial concern was to understand observed deflagration of fuel resulting from introduction of a pyrotechnic charge from the valve into the fuel with the objective to avoid this catastrophic event in space vehicle propulsion systems on future missions. However, the introduction of a new interference fit type ram to minimize pyrotechnic blowby into the fuel line results in new reliability concerns. As a result, the test program was expanded to look at various types of interference fit rams and NDE inspection techniques that can be used to evaluate flight valve integrity.

Test data obtained since 1996 provide the technical basis of a NASA Pyrovalve Handbook that is being drafted and will ultimately be converted to an AIAA Pyrovalve Handbook to be sponsored by the AIAA Energetic Components and Systems Technical Committee. A parallel effort to develop NASA and AIAA Pyrotechnics Training Courses is also underway.

Planned Future Activities

The importance of WSTF's continued active participation in the activities of the Voluntary Consensus Organizations cannot be overestimated. The technologies that provide the basis for standards development have been and will continue to be developed at WSTF. It is also in the best interest of NASA that WSTF participation assures that those requirements of importance to NASA operations and facilities remain intact. This is especially important in the beginning phases of the standards committee where the membership development goal of achieving equal participation from government, industry, and academia to assure consensus is critical.

The transition of WSTF technical manuals, available in the form of VCO Special Project Reports to Technical Guides requires the participation of WSTF technical personnel, especially those individuals that developed the information through test and analysis of test data. The subsequent conversions to Recommended Practices and Standards shall require some but significantly less involvement.

Finally, safety research and development must continue at WSTF in order to answer the many inquiries we receive from industry and to gain a better understanding of very complex technical issues associated with the safe use of aerospace fuels and oxidizers. This effort and our expanding efforts in providing hazards analysis and training will maintain WSTF as a key element in the aerospace community in the future.

SUMMARY AND CONCLUSIONS

The goal of this paper has been to inform aerospace researchers and engineers of improved opportunities for communicating safety concerns and to raise awareness of WSTF's continuing involvement in aerospace safety standards development. The nexus of propellant activities for oxygen, hydrogen, and hypergol safety underway at WSTF can aid researchers with locating critical information, expertise, testing services, and training. The authors encourage those who have a stake in making this kind of information available to their own organizations to participate in VCO activities, such as the ASTM Committee G4 and the AIAA Liquid Propellant Committee on Standards. For hydrogen, readers are encouraged to contact AIAA and/or the WSTF Propellant Hazards Program for further information.

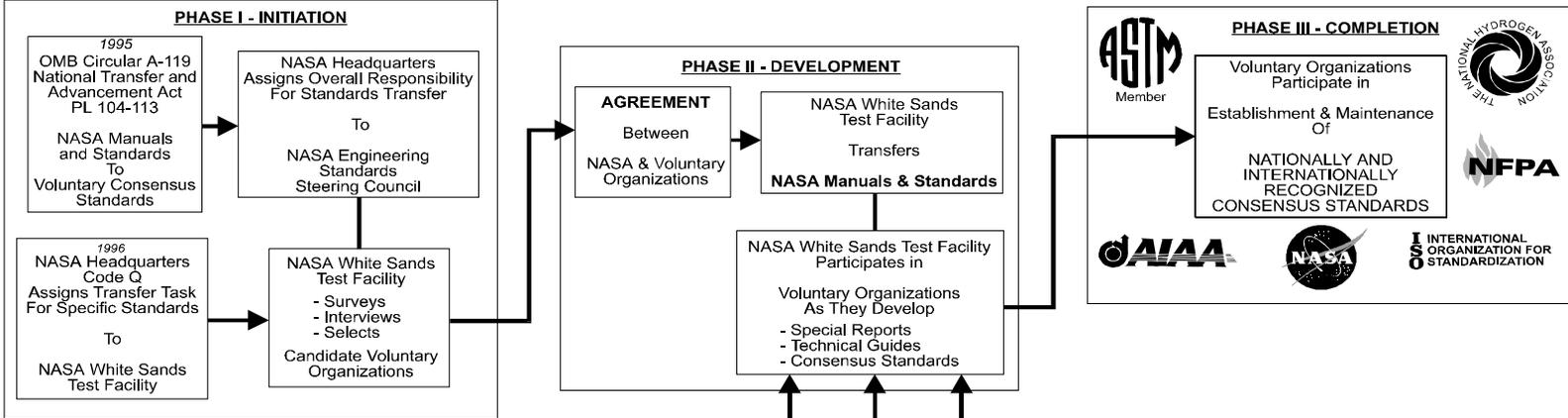
The NTTAA has pointed the way for reconsideration in the way government and industry interact. For the maximum benefit to accrue in the propellant safety arena, industry and government representatives must participate through the technical committees of the VCOs chartered to manage this information.

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STANDARDS DEVELOPMENT PROCESS



TECHNOLOGY TRANSFER PROCESS

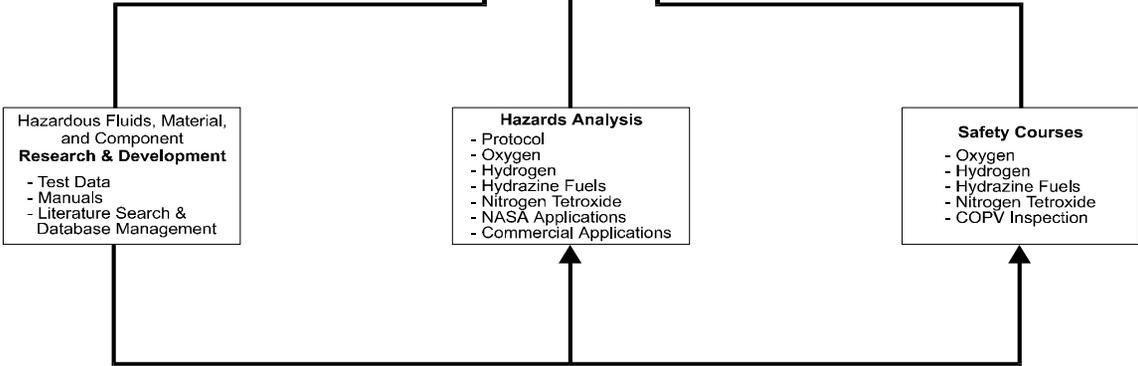


Figure 1. JSC WSTF Standards Development and Technology Transfer